DNS of turbulent boundary layer with time-periodic blowing through a spanwise slot

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Extended abstract

Direct numerical simulations are extended to see the effects of time-periodic blowing frequency from a spanwise slot on a turbulent boundary layer. Main emphasis of this study is placed on the blowing frequency effect on near-wall turbulent flow structures downstream of the spanwise slot. The Reynolds number based on the momentum thickness at inlet is Re_θ=300, and the slot width is approximately 100 wall units. The localized time-periodic blowing is given by changing the vertical velocity on the spanwsie slot. The blowing frequency is in a range of $0\leq f^+\leq 0.08$ at a fixed blowing amplitude (A^+=0.5). The frequency responses are scrutinized by examining the phase- or time-averaged turbulent statistics.

As shown in Fig. 1, the domain size is $200\theta_{in}\times 30\theta_{in}\times 40\theta_{in}$ in the streamwise, wall-normal and spanwise directions, where the corresponding mesh size is 257×65×129. The mesh is uniform in the streamwise and spanwise directions, but a hyperbolic tangent stretching is used in the normal direction to cluster points near the wall. The mesh resolutions are $\Delta x^+\approx 12.40$, $\Delta y^+_{min}\approx 0.17$, $\Delta y^+_{max}\approx 23.86$, and $\Delta z^+\approx 4.96$, based on the friction velocity at the inlet. Realistic velocity fluctuations at the inlet are obtained using the method of Lund *et al.* [1]. The convective outflow condition $(\partial u_i/\partial t)+c(\partial u_i/\partial x) = 0$ is used at the exit, where c is taken to be the mean exit velocity. A no-slip boundary condition is imposed at the solid wall. At the free-stream, the conditions $u=U_\infty$ and $\partial v/\partial y=\partial w/\partial y=0$ are imposed. Periodic boundary conditions are used in the spanwise direction. The spanwise slot for periodic blowing extents from $x=75.8\theta_{in}$ to $x=82.0\theta_{in}$, where the location of the inlet is defined as x=0. The slot width is $b^+\approx 100$ in wall units. The periodic blowing at the slot is generated by varying the wall-normal velocity according to the equation:

$$v_{slot}/U_\infty = A(1+\cos 2\pi ft) \tag{1}$$

The maximum blowing velocity (v_{slot}=2A) is imparted at t=0/4T and the minimum (v_{slot}=0) at t=2/4T, where T is the blowing period. At t=1/4T and 3/4T, the blowing velocities are the same as that of steady blowing with decelerating and accelerating phase, respectively. The amplitude of periodic blowing is A^+=0.5 in wall unit, which corresponds to the value of v_{rms} at y^+=15 without blowing. The blowing frequency ($f^+=f\nu/u_{\tau,in}^2$) varies in a range $0\leq f^+\leq 0.08$, where $u_{\tau,in}$ is the friction velocity at the inlet. The governing Navier-Stokes and continuity equations are integrated in time by using a fractional step method with an implicit velocity decoupling procedure [2]. A second-order central difference scheme is used in space with a staggered mesh. The Reynolds number based on the momentum thickness at the inlet is Re_θ=300. The computation time step is $\Delta t U_\infty/\theta_{in}$=0.3, which corresponds to $\Delta t^+\approx 0.25$ in wall units. The total time over which statistical averages are calculated is $T_{avg}=18000\theta_{in}/U_\infty$, which corresponds to 150, 460 and 1250 periods for f^+=0.01, 0.03 and 0.08, respectively.

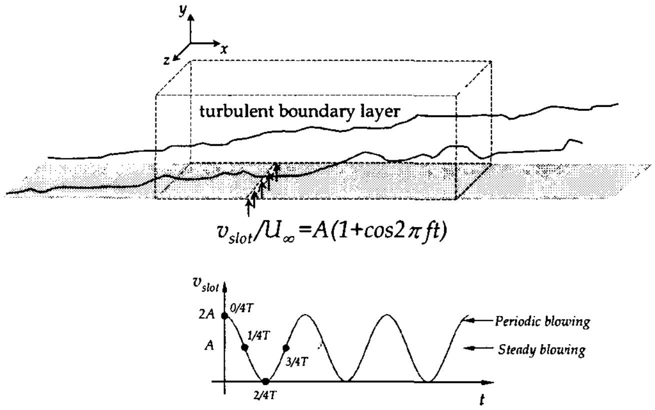

Fig. 1. Schematic diagram of the computational domain

An effective blowing frequency is observed at $f^+=0.03$, which gives the minimum value of the energy partition parameter K^*. The time-averaged streamwise velocity and wall pressure are invariant with the blowing frequency. However, the time-averaged skin friction and rms of wall pressure fluctuations are sensitive to the blowing frequency. Furthermore, the recovery of skin friction is fast at $f^+=0.03$. A region of strong negative spanwise vorticity is formed above the slot due to the periodic blowing and convects downstream as time goes by. For $f^+=0.03$, the lifted vorticity layer convects to lesser extent as compared with $f^+=0.01$. This may be attributed to the fact that the time difference between the accelerating and decelerating phases becomes smaller with increasing the blowing frequency. Thus, a newly generated strong spanwise vorticity coexists with the weaker prior one which convected in the decelerating phase of the previous period. For $f^+=0.08$, however, the time difference is so small that the afore-stated unsteady responses, such as the convection of the strong negative spanwise vorticity, are not found. The maximum increase of u''_{rms} is located closer to the slot than those of v''_{rms}, w''_{rms} and $-u''v''$. The increase of u''_{rms} for $f^+=0.03$ is smaller than those for other frequencies, whereas the increases of v''_{rms}, w''_{rms} and $-u''v''$ for $f^+=0.03$ are larger that those for other frequencies. This suggests that $f^+=0.03$ is the most effective blowing frequency in promoting the energy redistribution. The time-averaged streamwise vorticity fluctuations $\omega_x''_{rms}$ is most enhanced at $f^+=0.03$, which activates the near-wall vortical structures.

References

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